

# *The Game (Introduction to Digital Physics)*\*

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In the present brief article we introduce the main idea of Digital Physics in the form of an abstract game.

## **1 Introduction**

Let us imagine two computer programmers playing the following strange game:

Each of the programmers has his/her own computer, and they both sit in front of each other in such a way that they are able to see each other faces but not what is going on on the screen of the “opponent’s” computer.

They both program something and their computers are powerful enough (i.e. have sufficient memory) to permit them to complete their tasks.

The first programmer, let us call him “God”, has the right to program whatever He likes, as far as it can be represented on the screen as a cellular automaton (CA)<sup>1</sup>. He also has the right to “choose” some initial configuration (IC) for His CA, whatever He likes, as far as the configuration is a finite one.

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\* This article is a part of [Petrov 2002].

<sup>1</sup> Probably the best known cellular automaton is Conway's “Game of Life” [Gardner 1970, Berlekamp 1982]; for a good introduction to cellular automata in general, check out [Wolfram 1984].

(And this is everything that “God” must do, i.e. He makes no further “moves” in this Game. He simply “invents” some CA, some finite initial configuration within that CA, and then sits comfortably in His chair enjoying what is going on His screen, waiting for the other programmer to complete his “turn”...)

Similarly, the other programmer, let us call him “scientist” (or even: “digital physics scientist”, for a reason that shall become clear later) makes his “move” by programming his computer to show some CA on the screen starting from some finite initial configuration.

The “scientist” tries to “choose” such a CA and finite IC within it that is either the same as (i.e. “isomorphic” to) the CA and IC programmed by his opponent (“God”) or, at least, his CA and IC are programmed in such a way that when the time passes, “scientist’s” CA is able to *emulate in real time*<sup>2</sup> what is going on the “opponent’s” (“God’s”) screen.

(Actually, we can even think that both programmers play the game “in parallel”, i.e. there is no need to assume that “God” makes His “move” first, He “informs” the other programmer He is ready with His “almighty CA”, and only *then* the “scientist” makes his “turn”. No! We can safely assume that *both* players are simply programming their “CA plus IC” in parallel, and when both are ready we can check out what is the ‘result’ of the whole Game...)

We shall say that “God has won the Game”, if the God’s “CA+IC” are either different or, at least, “non-emulatable” by the scientist’s “CA+IC”.

Otherwise, of course, we say that “the scientist has won the Game” against God, and what is on the scientist’s screen is actually a TOE, a “Theory of Everything”.

## 2 Historical notes

This popular explanation (in the form of a game) is probably the shortest possible way we can introduce the main idea of a relatively new scientific field, a crossing between theoretical computer science and theoretical physics, known as “Digital Physics”.

(That’s why we call our “scientist” also a “digital physics scientist”...)

A little bit of history:

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<sup>2</sup> A CA is said to emulate another CA “in real time” if there is a constant  $c$  such that the following holds: for every configuration of the first CA at time steps  $t_0 < t_1 < \dots < t_i$ , there exists an isomorphic configuration of the second CA at time steps  $t'_0 < t'_1 < \dots < t'_i$  where  $t'_j - t'_{j-1} = c(t_j - t_{j-1})$  for  $1 \leq j \leq i$ . Emulation in real time is a term proposed by Schönhage [Schönhage 1980]. For brevity, later in this article and in all articles from this series [Petrov 2002] we shall talk merely about “emulation” instead of “emulation in real time”.

Sometime around 1960, Edward Fredkin, a professor from MIT, proposed the spectacular idea that our *real(!)* Universe is actually a giant cellular automaton [Wright 1988].

Originally, Fredkin's idea has been experimented with the facts known from contemporary physics. The basic method has been to "model" laws of physics using CAs as mathematical models, as well as to check out what kind of conjectures about our real world we can make assuming the possibility that both space and time are *discrete*, but not continuous, and that the laws of physics are *deterministic*.

This line of research is known as "Digital Mechanics" [Fredkin 1990] and has been developed by Fredkin and others for the past 40 years. It has led to a number of important results (for both computer science and physics), the most well-known of which is probably the so-called "Billiard Ball Model" (BBM) [Fredkin 1982] and the corresponding BBM CA [Margolus 1984].

The BBM CA is a theoretical model that shows that (in principle) there is no problem in constructing a universal computer that dissipates no energy while making computations.

In more general terms, BBM CA and the (larger) class of so-called "Reversible Universal Cellular Automata" (RUCA) have been proposed as a discrete mathematical model of the second law of thermodynamics, as well as a possible clue to look for the solution of the more general problem of the Universe as a CA.

Fredkin's approach, i.e. "Digital Mechanics" (DM), is largely based on physics and what it suggests for our abstract CA-based mathematical models.

In 1993 the author of these lines proposed another idea, aimed directly at the point of finding the solution to the main problem of the "Universe as a CA" suggestion.

This idea, known as "Petrov's hypothesis", is a new way to look at the whole problem and what we usually know as "physics".

The idea gave birth to another interesting line of thought and research, known as "Digital Physics" (DP).<sup>3</sup>

In DP, we assume the suggestion made by Fredkin is correct, and we call it "Fredkin's thesis".

However, instead of trying to use facts from contemporary physics, Petrov's hypothesis suggests it might be possible to re-construct "The CA" that is supposed to be an exact informational model of our Universe *without* looking into... *any(!)* physics.

DP uses a *completely* new idea to look at the whole of physics, as we know it; namely, DP is a *non-experimental* physics.

DP is a "computer scientist's" look at physics, a strange "physics" without... *any* physics at all!

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<sup>3</sup> In his earlier works Fredkin also speaks about "Digital Physics"; we have no pretensions on the "mental copyright" of the term used. In the present text, we merely use "DM" and "DP" abbreviations in order to distinguish between the two *methods* (or "viewpoints") to look at the whole problem, where DM denotes Fredkin's approach, and DP – the approach proposed by the author.

The task of DP, as we see it, is to find at least one possible combination of “CA plus IC” (actually, an ordered pair  $\langle CA, IC \rangle$ ) that “solves” the Game described above...

### 3 Conclusion

But let us get back to the Game.

Someone may say:

“This Game is a meaningless one! The ‘scientist’ can always win the Game, if he merely chooses some computationally universal CA, i.e. UCA. For example, the scientist can choose the Game of Life (GOL) as a CA, and since GOL is known to be an UCA<sup>4</sup>, he can be sure he wins the Game!”

No, it is not that easy!

The Game has some subtle element within it that most people usually do not pay enough attention to when they first start thinking about it... But that component of the Game is really a *very* important one!

Please note that we want “God” and “scientist” not only to “choose” some CAs; we also want them to choose some finite ICs within their CAs, too!

And what they “choose” is their final choice, i.e. they have no right to “change their mind” and decide to “choose something else” in the “future”.

CAs are *fixed*, ICs are *fixed*, too!

(So to speak, “the dice has been rolled”, and there is no turning back!)

So, please note now that it is not sufficient for the “scientist” to choose some UCA, like GOL, for example. Since if he chooses the GOL as a CA, but then pays no attention to his IC, he may choose something as simple as a “still configuration”, “traffic lights”, or a lonely “glider” traveling in a void space full of “zeros”...

(For simplicity, let us concentrate on the last proposed choice: a lonely glider)

Let us assume also, for the moment, that “God” Has decided to choose GOL as well.

But clever God may decide to choose *two* (or more!) gliders (as an initial configuration) that collide at some point in the CA space, giving birth to something as chaotic as one is able to think about!

So, who will be the winner? God or the scientist?

Of course, God wins the Game in this case: His CA might be identical to the CA of the scientist, but still, what is going on His screen is in no way compatible with the simple computational process taking place on the scientist’s screen. To be more

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<sup>4</sup> The classical reference for Conway’s “Game of Life” (GOL) is [Gardner 1970]; the proof that GOL is a universal cellular automaton (UCA) is in [Berlekamp 1982].

precise: what is going on on God's screen, in this case, *cannot* be *emulated* on the scientists screen, and that's for sure!

The lonely glider, traveling in the void space of the GOL, is certainly *not* something even getting close to what one usually imagines as a "complex computational process". No doubt, it is not!

That is why we can talk about a "(computationally) universal IC" (UIC) that lies within some (fixed) UCA. The task of DP, in this sense, is to find at least one UCA and some UIC within it. A hard task, indeed!

Still, not everything looks so "impossible" when one starts to think seriously about it, and, especially, when he/she starts thinking about the so-called "Petrov's hypothesis", proposed by the author of these lines.

Let us call the ordered pair <UCA, UIC> and the following computational process (that starts from UIC and takes part in that particular UCA) a "universal algorithm". Without looking too deeply into the technical details, what Petrov's hypothesis says, in short, is that there exists a *single*(!) "universal algorithm", and *that* algorithm is actually *The Algorithm* of our Universe!

That is the whole point; that is what DP *is*.

Actually, it is unimportant whether we shall write "universal algorithm" or "Universal Algorithm" (i.e. *The Algorithm* that runs our *real* Universe), since they both turn out to be one and the same thing...

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